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THE MEASUREMENT OF TRANSLUCENCY OF CERAMIC BODIES BY THE USE OF A PHOTO-ELECTRIC CELL

BY

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

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THE MEASUREMENT OF TRANSLUCENCY OF CERAMIC BODIES BY THE USE OF A PHOTOELECTRIC CELL

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I. INTRODUCTION

The old method of measuring translucency in which a potter puts his finger behind a plate and observes its shadow, is acknowledged by all to be very crude and unsatisfactory. Various other methods have been proposed but there seems to be no agreement among the various experimenters, as to which method is the best. Most of these methods depend upon the sliding of a wedge-shaped specimen past a slot, behind which is a light of a certain power and marking the point on the wedge where the light just disappears. The thickness of the specimen at that point is taken as a numerical expression of the translucency. It can be readily seen that such methods are not a real measure of translucency, but only a relative measurement since there is no end point and the ability of various people to judge the disappearance of a light would introduce a personal factor which could not be corrected for.

The object of this work is to devise a method of measuring translucency by the use of a photoelectric cell.

II. OTHER METHODS USED IN MEASURING TRANSLUCENCY

Various methods which have been used in measuring translucency of ceramic wares are as follows:

Ashley [1] held wedge shaped pieces close to an electric or incandescent light and outlined the translucent area with a pencil. The thickness is then calipered.

Ogden [2] measured the translucency of the thickness of the body necessary to shut out the light of a 16-candle-power incadescent lamp. A box of sufficient size held an electric lamp. One side of the box was of zinc, in which there was a narrow slit about half an inch long. Wedge shaped pieces were moved up and down past this slit until the light was just shut off. The thickness of this point on the wedge was then calipered.

Williams[3] and Ashley used a different method than any of the above mentioned in measuring the translucency of white ware samples. A series of screens which varied in size from 1/4 inch downward were placed at a distance of about 3 inches from an incadescent light, with a reflector. Samples of white ware were held flat against the wires . The smallest mesh distinguishable through a specimen was noted and the thickness of the piece measured. They proposed that a standard test for translucency be established, using a standard series of screens with regular variations in size with a constant ratio in the diameter of the wire and width of opening. A lamp of standard intensity would also be used.

Parmelee and Baldwin[4] placed a lamp bulb within and immediately below a slot cut in the top of a wooden box. Wedge shaped specimens were placed over the slot and it was possible to determine when, in the scale of mixtures, translucency began and whether it increased or decreased with varying compositions. A fine wire was also interposed between thelight and the trial pieces. This wire could be clearly seen while in a stationary position with pieces of high translucency, but in pieces of low translucency it could not be detected unless it was moved across the illuminated field.

Watts[5] determined the translucency of wedge shaped specimens by placing them over a 1" hole in a box containing a 16 candle power incadescent lamp of constant brilliancy. The maximum thickness of the trial piece expressed in centimeters, through which a No. 20 wire could be detected on the face of the trial next the lamp, with the lamp 3 inches distant, was taken for the measurement of translucency.

Lin[6] arranged wedges of different body mixtures in a row. A good light was placed behind them. A metal wire about 1 mm. in diameter was held close to the lighted side of the wedge under examination. The thickness of the wedge, at the point below which the wire became invisible, was measured by means of an Arnes dial.

Bleininger[7] suggested that translucency might be measured by means of a selenium cell which has the property of having its conductivity lowered as light falls upon it. Such a method is used in astronomy for measuring and comparing the various light

intensities of stars. No details of the plan were worked out.

Priest[8] describes an apparatus used in grading tracing cloth, by covering a standard black and white panel with a piece of tracing cloth, and with a suitable photometer, measuring the ratio of the brightness of each color. It was advocated that this method could be used to measure the translucency of porcelain disks, but the details were not worked out.

A method of measuring translucency by means of a photometer, is advocated in "Pottery Industry", Department of Commerce Miscellaneous Series, No. 21. The variation in translueency is represented by the light transmitted through the specimen from a standard lamp. This is expressed in percentage of the candle-power of the standard. A thickness correction affords only a rough approximation, since it is evident that the light transmission is not diminished in direct proportion of the specimen. The true correction factor has not yet been established.

III. EXPERIMENTAL

1. The Photoelectric Effect.- The emission of negative electrons from an illuminated plate is generally known as the photoelectric effect. The alkali metals are particularly sensitive and for this reason are used in measuring light of low intensity.

The rate at which these negative electrons are emitted is variable depending upon the pressure, nature of the gas around the plate, state of polish of the surface and the length of exposure.

The current produced can be largely increased by making use of ionization by collision in the surrounding gas. Cells containing some inert gas, such as argon, have been used to measure the light radiation from a candle at a distance of three miles.

2. Description of Apparatus.-

(a) The Photoelectric Cell. The photoelectric cell used in the experiment was made by Dr.Jacob Kunz of the Department of Physics, University of Illinois. Silver was vaporized and then allowed to condense in a thin film over all of the inside of the cell except a round opening for the admittance of light. Potassium was then vaporized and upon condensing a thin film was formed over the silver film. This formed the cathode or negative terminal of the cell.

The anode consisted of a hoop of platinum wire, directly in front and a few centimeters from the cathode.

The cell was filled with argon, a gas which is generally used when very sensitive measurements are to be made.

A resistance of 100,000 ohms was connected in series with the cell, in order to protect it from a sudden increase in voltage.

The action of the cell was as follows, light was allowed to strike upon the cathode and negative electrons were given off from the potassium. When a difference of potential was maintained between the anode and the cathode, these negative ions flowed toward the anode. The current produced was measured by a sensitive galvanometer.

The photoelectric cell was placed in a small light-tight-box, 12 in. by 6 in. by 3 in. A round opening 7/8 in. in diameter was made in one side of the box. This opening could be closed and opened at will by means of a sliding shutter, allowing the light to fall upon the cathode of the cell.

This box was placed in a large wooden box which was also light-tight and painted black inside. This larger box measured 2 1/2 ft. by 2 ft. by 2 ft. and contained in addition to the photo-electric cell, the source of illumination and a lens to make the rays of light parallel.

The source of light was a Mazda 25 watt point bulb. For specimens of low translucency a stronger light would have been preferrable. The light rays were made parallel by means of a lens which focused the light strongly upon the 7/8 in. opening of the box containing the photoelectric cell. It was found that best results were obtained with the light 18 inches from the photoelectric cell and the lens between the two, its focal length being such as to focus the light sharply upon the specimen.

(b) The Galvanometer.- The galvanometer was of the D' Arsenval type with the following characteristics :

Sensitiveness - 2.711 megs. or a figure of merit of about 10^{-12}.

Period - 6.8 seconds

Resistance - 500 ohms.

(c) Voltage.- The source of voltage consisted of flat flash-light batteries of the French four-cell type, connected in series. Each cell had a strength of 4.5 volts.

(d) Set-up of Apparatus.- The anode of the photoelectric cell was connected in series with a resistance coil, having a resistance of 100,000 ohms, then directly to the galvanometer.

The cathode was connected directly through a mercury switch to the negative end of the source of voltage. This mercury switch made it possible to turn the current on and off easily and quickly. The positive end of the flash-light cells was connected directly to the galvanometer.

A damping key was of great aid in shortening the swing of the galvanometer and enabled a reading to be made quickly and accurately.

3. Preparation of Bodies.- The composition of the body mixtures as shown in Table No. I, consisted of feldspar from Abingdon Pottery, flint and clay. The clay content was made up of 1/3 Tennessee ball clay No.3., 1/3 Harris North Carolina Kaolin and 1/3 Florida Kaolin.

A 2-kilogram batch of each corner body was weighed

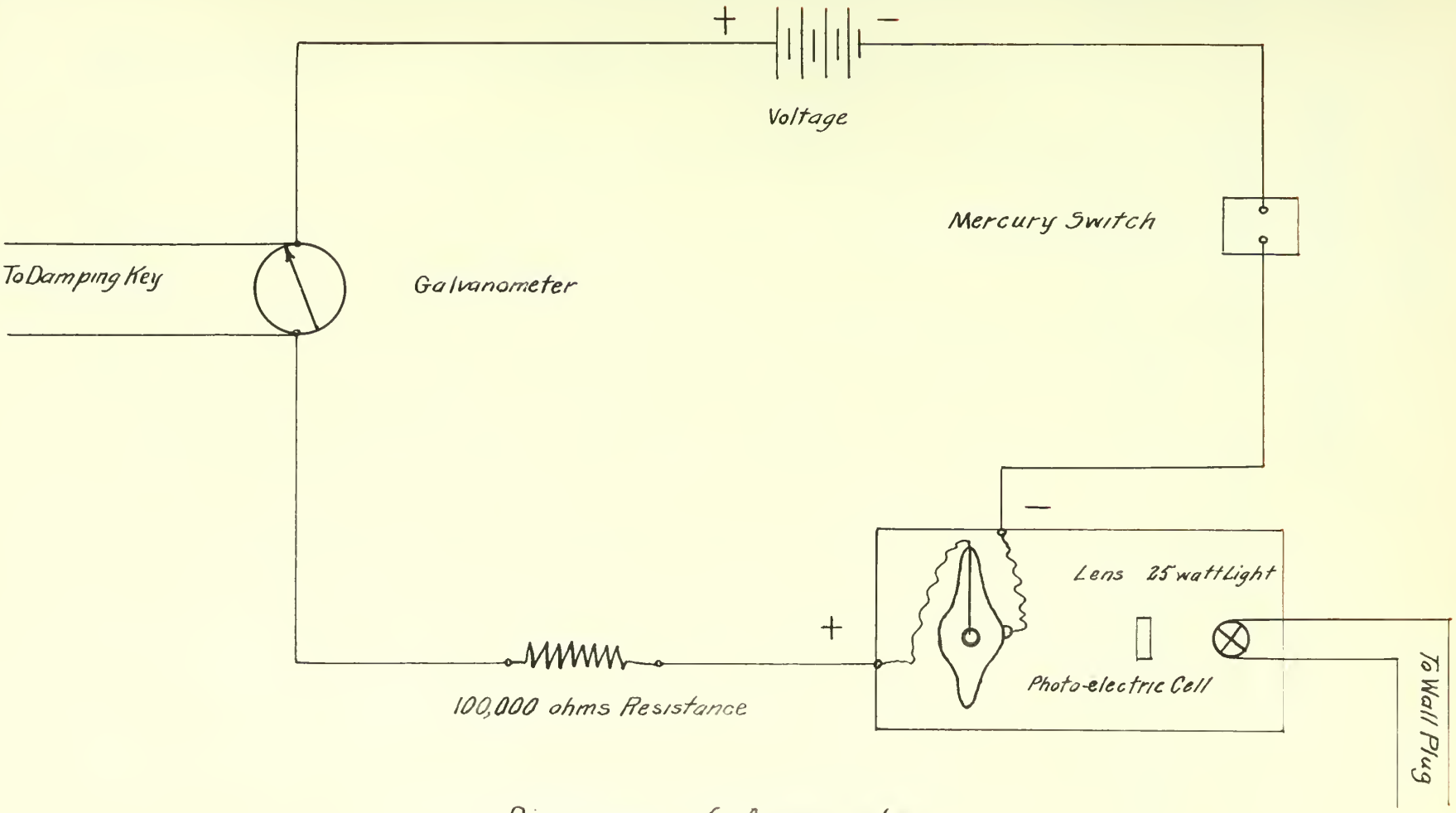


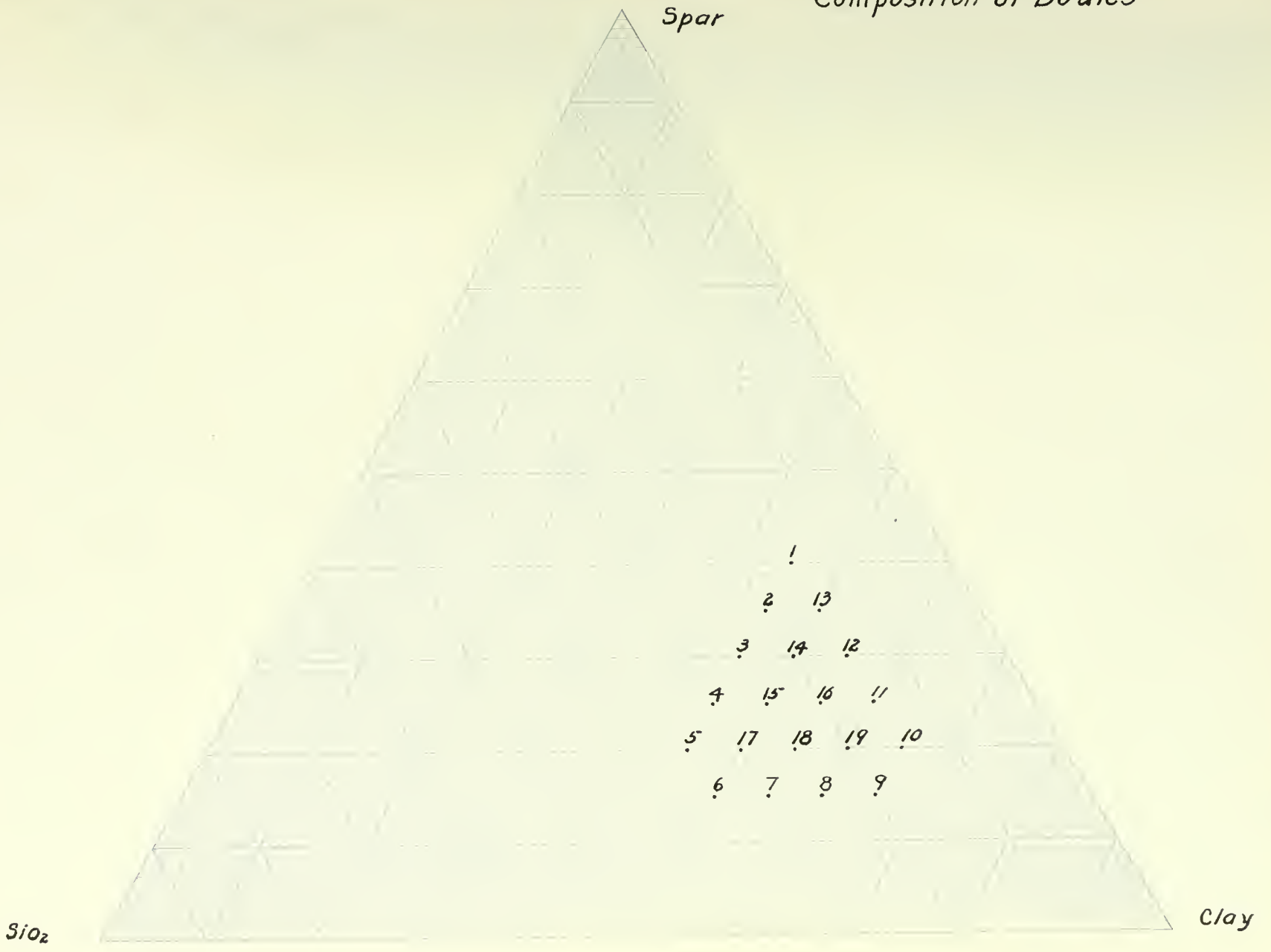
Diagram of Apparatus

TABLE NO.I

COMPOSITION OF BODIES

Body No.	Feldspar	Flint	Tenn. Ball No.3	No.Carolina Kaolin	Fla. Kaolin
1	40	15	15	15	15
2	35	20	15	15	15
3	30	25	15	15	15
4	25	30	15	15	15
5	20	35	15	15	15
6	15	35	16 2/3	16 2/3	16 2/3
7	15	30	18 1/3	18 1/3	18 1/3
8	15	25	20	20	20
9	15	20	21 2/3	21 2/3	21 2/3
10	20	15	21 2/3	21 2/3	21 2/3
11	25	15	20	20	20
12	30	15	18 1/3	18 1/3	18 1/3
13	35	15	16 2/3	16 2/3	16 2/3
14	30	20	16 2/3	16 2/3	16 2/3
15	25	25	16 2/3	16 2/3	16 2/3
16	25	20	18 1/3	18 1/3	18 1/3
17	20	30	16 2/3	16 2/3	16 2/3
18	20	25	18 1/3	18 1/3	18 1/3
19	20	20	20	20	20

Composition of Bodies



up, i.e., Nos. 1, 5, 6, 9 and 10. Three thousand cc. of distilled water were added and the whole was ground in a ball mill for two hours. The ball mill was about half full of pebbles. A speedometer indicated the exact number of rotations of the ball mill and in this way each body received the same amount of grinding.

Upon removal from the ball mill, the bodies were put through a 120-mesh screen , only a slight residue was left in any case, consisting of impurities from the ballclays.

The dry content of each body was determined by evaporating a weighed amount of slip to dryness and then reweighing.

The other bodies were prepared by blending, Nos.2, 3 and 4 from Nos.1 and 5; Nos. 11, 12 and 13 from Nos. 1 and 10,etc.

4. Preparation of Specimens.- Attempts were made to cast thin specimens 5 cm. by 10 cm. and 1 - 2 mm. thick, in a plaster of paris mould with the slips as thus prepared. Trouble was encountered at once, due to the fact that air bubbles held in the slip, came to thetop of the cast specimens and left a very rough irregular surface. Attempts to polish off these indentations reduced the specimens to such a thinness, as not to be useable.

This trouble was overcome by pouring each slip into a two liter flask and exhausting the air from it by means of a vacuum pump. Shaking the slip from time to time hastened the removal of the air.

It was found that slip with a specific gravity of 1.46 to 1.50 gave the best test pieces.

Specimens measuring 5 cm. by 5 cm. and 1-2 mm. in thickness were cast, and, upon removal from the mould were allowed to

dry in the air to a bone dry condition. They were then preheated in a small muffle kiln to 1000°C. It was then possible to handle the specimens without breaking them and any irregularities on the surface were polished off.

They were then imbedded in calcined flint and burned at Cone 10 in a coal fired down-draft test kiln. The duration of the burn was 36 hours.

5. Method of Procedure.- Specimens were held in place, covering the 7/8 in. opening in the photo-electric cell box, by means of two brass clamps. When the shutter closed, the circuit was completed by means of the mercury switch and a zero reading was taken on the galvanometer. The shutter was then raised, allowing the light to fall directly upon the specimen. The light which was transmitted through the specimens, fell directly upon the photo-electric cell and the deflection was measured upon the galvanometer. Ten readings were taken upon each specimen and the mean of these taken as the true deflection. The circuit was broken by "cutting out" the mercury switch, and the galvanometer was allowed to swing back to zero after each reading.

The variations in the ten readings were small, being no larger than 1 1/2 millimeter in any case.

The thickness of each specimen was then measured by means of vernier calipers. Measurements were taken from each of the four corners of the specimen and the mean taken as the true thickness of the specimen.

The thickness of the specimens varied from 1.2 mm. to 3.0 mm. The deflection in mm. upon the galvanometer, multiplied by the thickness in mm. was taken as the deflection for a thickness of one millimeter.

It was found that 130.5 volts was the maximum which could be used with the photo-electric cell. A higher voltage gave such a large deflection that it could not be measured upon the galvanometer scale.

DATA SHEET - TABLE NO.2

Body No.	Thickness in mm. A	B	C	Deflection in mm. A	B	C	Deflection per mm. thickness A	B	C	Average
1	1.2	2.52	1.91	16.9	7.1	9.7	20.03	18.0	18.6	18.87
2	2.23	1.43	1.8	6.05	12.7	8.41	13.5	16.2	15.1	14.93
3	2.35	3.15	1.71	6.3	4.18	8.17	14.8	13.3	14.0	14.03
4	2.1	1.95	2.21	2.9	3.3	3.17	6.1	6.44	7.01	6.51
5	2.08	1.51	-	4.0	5.24	-	8.05	7.92	-	7.98
6	1.74	2.02	1.73	2.57	2.1	2.52	4.48	4.24	4.33	4.41
7	1.64	1.74	2.13	3.05	2.5	1.91	5.0	3.75	4.06	4.27
8	2.68	2.11	1.9	1.01	1.37	1.61	2.69	3.16	3.06	2.97
9	1.71	1.59	2.32	2.87	6.25	1.75	4.9	9.95	4.05	4 47
10	2.97	2.94	1.47	2.15	2.16	4.84	6.23	6.3	7.12	6.55
11	1.98	1.51	2.2	4.1	7.8	3.14	8.13	11.8	6.93	8.95
12	2.31	2.27	2.28	3.8	3.53	2.0	8.78	8.14	4.55	7.15
13	1.84	1.89	2.41	4.1	4.7	3.36	7.55	7.72	8.10	7.79
14	1.99	2.39	2.12	7.95	6.61	6.99	15.8	16.0	14.71	15.51
15	2.29	2.33	1.31	3.89	4.09	5.36	8.9	9.52	7.03	8.48
16	1.77	1.72	2.92	5.0	4.9	2.61	8.85	8.5	7.62	8.32
17	2.11	2.2	1.81	2.89	3.2	4.02	6.09	7.04	7.3	6.81
18	2.47	1.86	1.34	3.3	219	5.79	8.15	5.57	7.77	7.16
19	1.93	1.43	2.19	3.9	5.88	3.09	7.51	8.31	6.78	7.53

IV. RESULTS

The results are shown in Table No.2. In specimens of high translucency a deflection of about 20 mm. was obtained, while in specimens of low translucency the deflection was as small as 1.5 mm. in some cases.

It was found that with a few exceptions , translucency was inversely proportional to the thickness of the specimen. This relation between translucency and thickness was also obtained by Ashley and Williams [9].

Graph No. 1 with a constant SiO_2 content, shows that there is a definite relation between translucency and the ratio feldspar to clay. Translucency increases with an increase in the ratio feldspar to clay, or we might say, with an increase of feldspar content. This is especially true in bodies of low SiO_2 content. A study of Graph No. 1 would seem to show that the increase in translucency with an increase in the ratio feldspar to clay depends upon the SiO_2 content. The increase is very rapid in low SiO_2 bodies, but decreases until at 35% SiO_2 only a slight increase is obtained.

Graph No. 2 with a constant clay content, shows that there is also a relation between translucency and the ratio feldspar to SiO_2, but that this relation depends upon the clay content of the body. A body of 45% clay content shows a rapid increase in translucency with an increase in the ratio feldspar to SiO_2, but in a body of 60% clay content, the increase is much smaller.

Graph No. 3 with a constant feldspar content does not seem to show any relationship between translucency and the ratio SiO_2 to clay content.

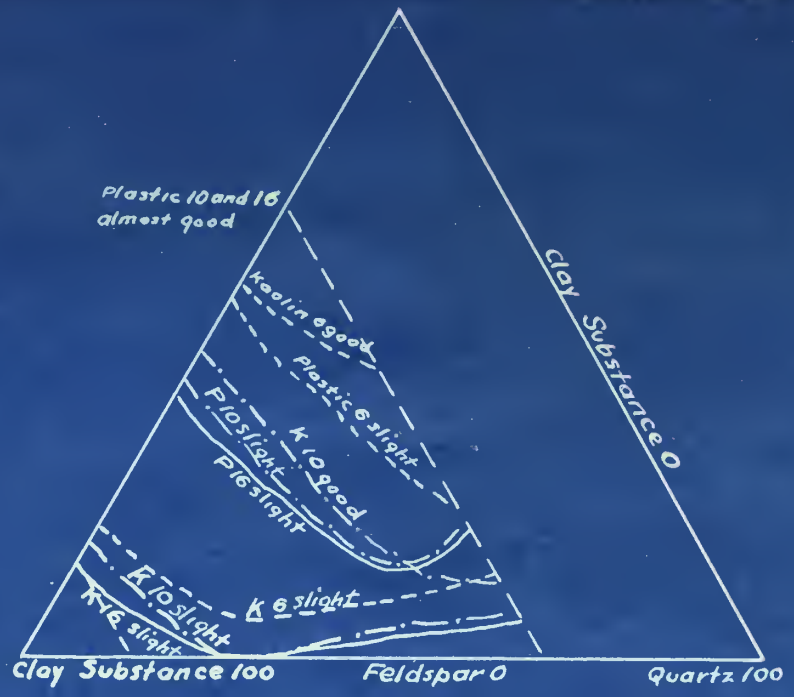
Figure No. 3 is a model whose height is regulated by the deflection obtained on the galvanometer for each point represented on the surface. A study of this model shows a gradual increase in translucency with an increase in feldspar content until a clay content of 30% is reached. At this point there is a sudden increase in translucency and than a gradual increase in translucency as the clay content decreases and the feldspar increases. This high translucency is reached much sooner upon the high silica side of the diagram. This sudden increase in translucency is hard to explain. It was thought that the presence of sillimanite crystals might explain this sudden increase, but an examination of several specimens under the microscope showed no trace of sillimanite crystals. These could hardly be expected at a temperature of Cone 10 (1330°C).

Dr.Hecht [10] (see Fig.4) examined bodies containing from 0 to 70% feldspar, 0 to 70% silica and 30 to 90% clay. He found that translucency began much sooner in high silica bodies than in low silica bodies, the clay remaining constant. This was verified as is seen in Fig.3 by the results obtained in this experiment.

Very similar results were obtained by various other investigators.

Ashley [11] states that translucency increases as the feldspar is raised and the clay substance decreases.

Purdy [12] found that translucency decreases with an



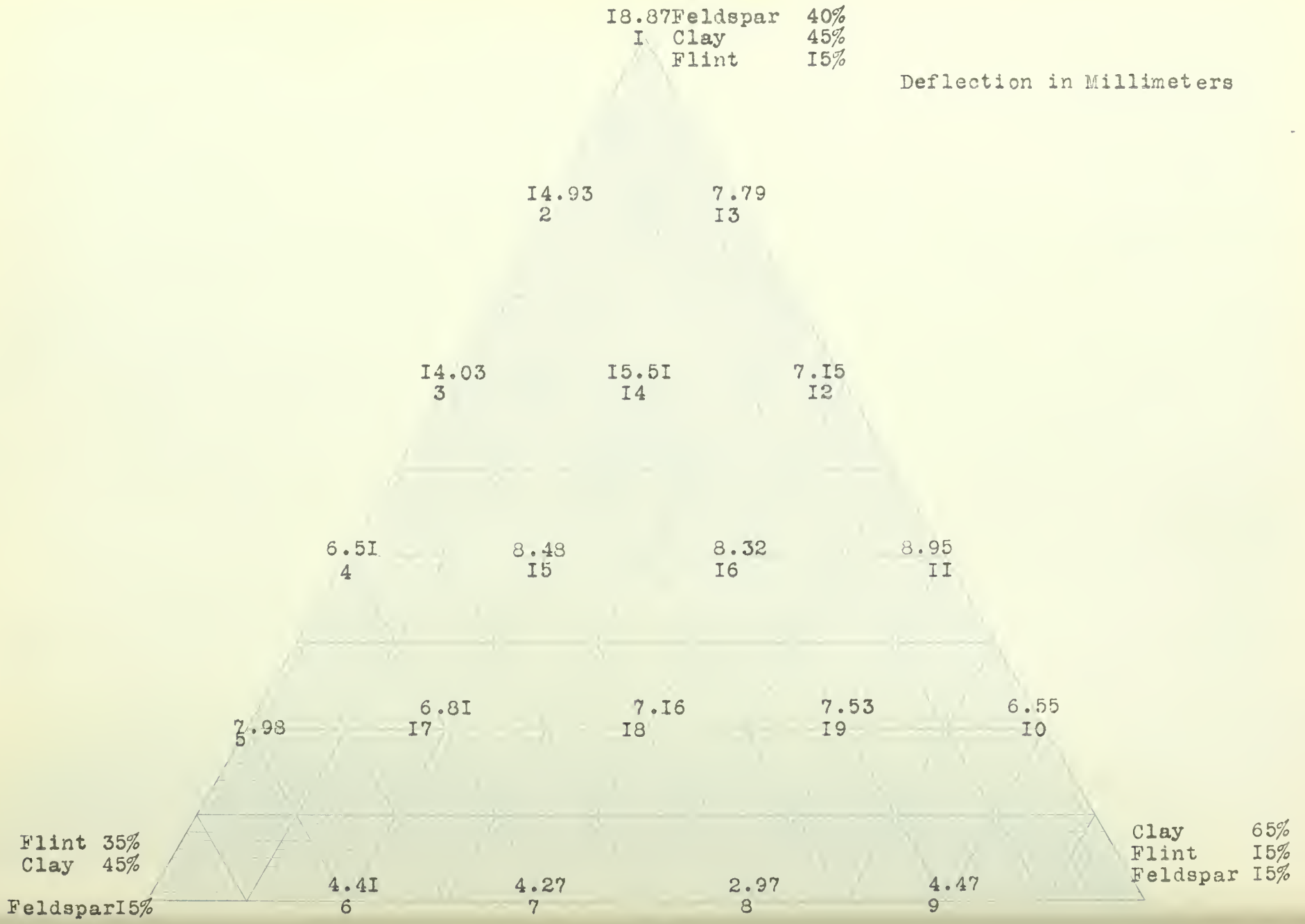
Limits of translucency
Results of cone 6 burn represented by dotted lines
Results of cone 10 burn represented by dot and dash line
Results of cone 16 burn represented by full line
All trials become more translucent as the feldspar is raised and clay substance diminished. The limits shown are those at which the first slight translucency appears and those at which the translucency becomes good. When the clay substance is half from kaolin and half from plastic clay substance, the results are intermediate between those shown here.

increase in clay.

Odgen [13] found that translucency was increased by keeping the clay content low and increasing the feldspar content.

Watts [14] states that translucency increases with soda feldspar content.

Lin [15] states that translucency increases with feldspar content and decreases with clay content.

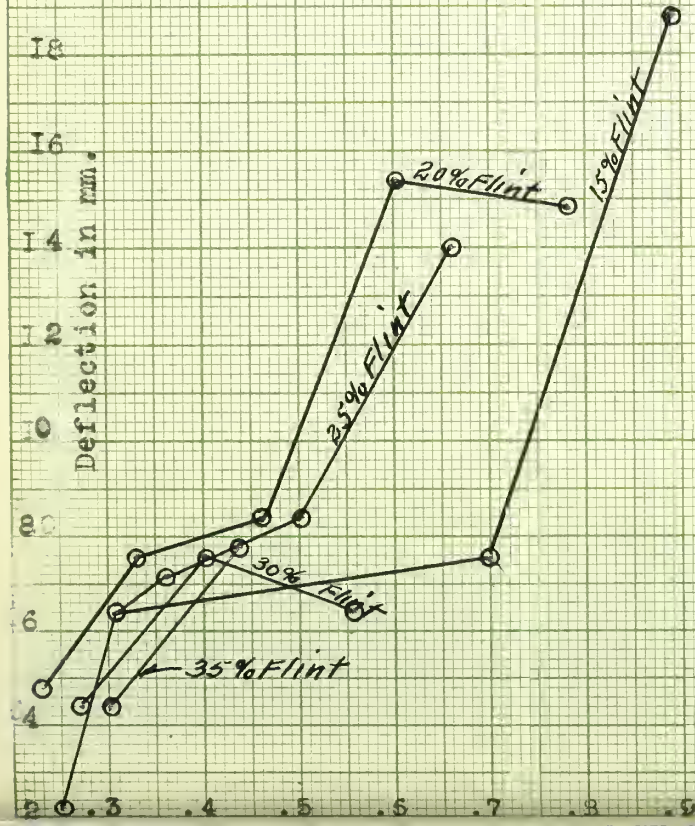

I8.87 Feldspar 40%
I Clay 45%
Flint I5%
Deflection in Millimeters
I4.93
2
7.79
I3
I4.03
3
I5.5I
I4
7.I5
I2
6.5I
4
8.48
I5
8.32
I6
8.95
II
7.98
5
6.8I
I7
7.I6
I8
7.53
I9
6.55
I0
Flint 35%
Clay 45%
FeldsparI5%
4.4I
6
4.27
7
2.97
8
4.47
9
Clay 65%
Flint I5%
Feldspar I5%

GRAPH NO I

Flint Constant

Deflection in mm. vs Ratio

Feldspar to Clay

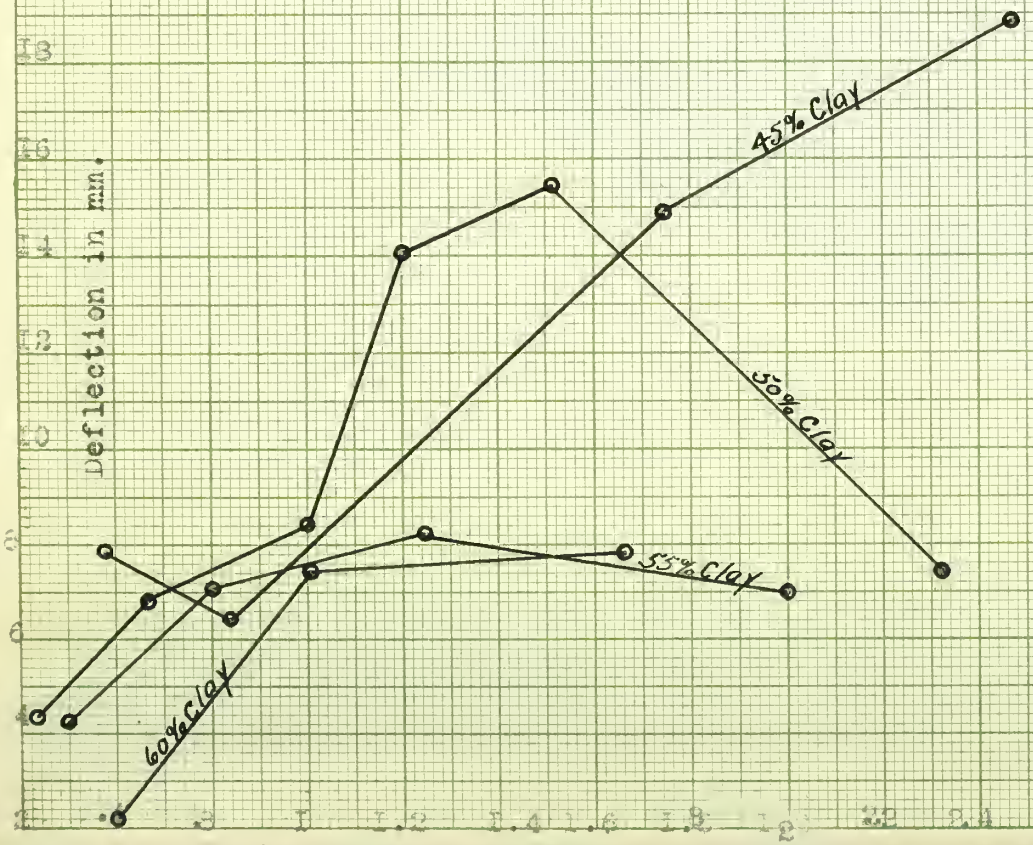


GRAPH NO. 2

Clay Constant

Deflection in mm. vs Ratio

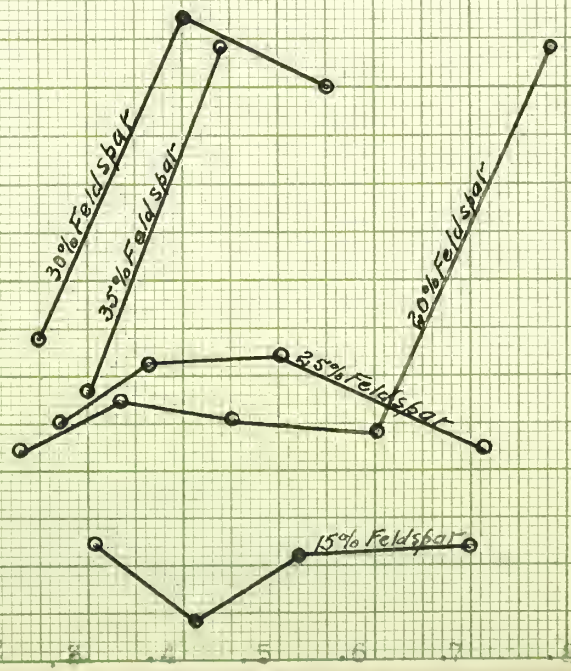
Feldspar to Flint



GRAPH NO. 3

Feldspar Constant

Deflection in mm. vs Ratio
Flint to Clay



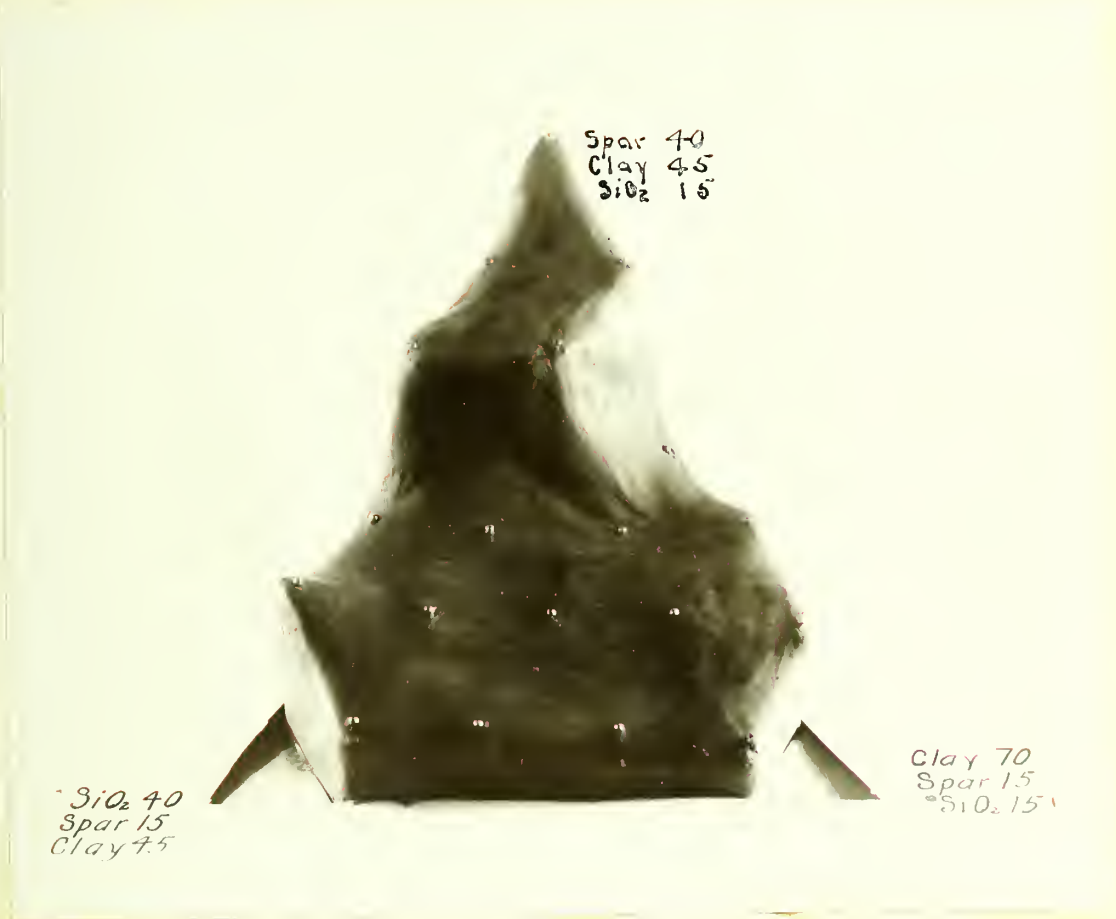

Spar 40
Clay 45
SiO_2 15
SiO_2 40
Spar 15
Clay 45
Clay 70
Spar 15
SiO_2 15

Figure No. 4

V. CONCLUSIONS

1. The photo-electric cell can be used to measure translucency of thin disks of ceramic mixtures. However, either a very sensitive cell or a very sensitive galvanometer would be required if specimens thicker than 3.5 millimeters were used. Damp weather decreases the sensitiveness of the photo-electric cell, making it necessary to take readings on clear days.

2. Translucency increases with an increase in the ratio feldspar to clay. The increase after a certain point is rapid in mixtures of low silica (15%) content, but is slight in mixtures of high silica (35%) content.

3. Translucency increases with an increase in the ratio feldspar to silica, the increase depending upon the clay content of the mixture. It is higher with low clay. With a clay content of 50% or above, the maximum translucency is apparently reached with a certain feldspar-silica ratio. After this point translucency decreases.

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